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Mortality during heatwaves 2003–2015 in Frankfurt-Main – the 2003 heatwave and its implications

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ABSTRACT

Heatwaves have always occurred, but they are expected to intensify in frequency, duration and intensity due to climate change. Germany (like most European countries) experienced a distinct heatwave in 2003. Afterwards local heat health action plans (HHAP) were implemented in numerous regions (for example in Hesse). This analysis was designed to compare the heat wave of 2003 with the following ones in 2006, 2010 and 2015. We discuss whether measures from the Hessian HHAP were effective in reducing mortality and identify specific characteristics of the 2003 heatwave which did not allow direct comparison.

Mortality and temperature data from the city of Frankfurt collected between 2003 and 2015 was used to answer the question of whether the implemented HHAP were effective, or if the mortality in 2003, pre-HHAP implementation, was especially high due to other factors.

Excess mortality in 2003 was considerably higher for the overall population than in the heatwaves of the following years (2003: 77.8%, 2006: 12%, 2010: 22.7%, 2015: 38.1%). Heatwaves did not result in a significant excess mortality at all in some years, e.g. in 2006. Aside from the mortality rate, the duration of the heatwave (2003: 12 days; 2006: 5 days; 2010: 5 days; 2015: 5 days) was the only differing characteristic, leading to the hypothesis that heatwave duration might be a better indicator of mortality during heatwaves, than other characteristics, alone or combined. In summary regarding the effectiveness of the HHAP remains inconclusive since the pre-HHAP heatwave of 2003 differed in certain characteristics (especially the longer duration). Furthermore, the activities representing the HHAP were diverse and were implemented stepwise over some years. The effects on mortality of individual activities cannot be evaluated.

Further research should consider differences, e.g. between places (climate zones etc.) and heatwave definitions.

1. Introduction

In 2003, a heatwave occurred in central Europe, which was the “hottest” since 1500 (Kovats and Ebi, 2006). Heatwaves are not a new phenomenon but they are gaining in importance due to their association with global warming and climate changes (Bernstein et al., 2007). Numerous investigations have dealt with the increase in mortality during that heatwave (Robine et al., 2012; Kovats and Ebi, 2006; Heudorf and Schade, 2014). In the years following heatwaves, some European countries implemented heat health warning systems (HHWS) and/or health protection action plans/heat health action plans (HHAP). Recent publications have tried to analyze the validity of these preventive measures which have for example included information leaflets and website information (Hajat et al., 2010).

Published research on heatwave related mortality are difficult to compare due to differences in the basis of measurement. Some analyses work with the definition of “heat-related deaths” per time interval (Johnson et al., 2016); others with the concept of “excess mortality”. Excess mortality can be calculated as the observed deaths minus the baseline deaths. Additional measures can be estimated, including the proportion of total deaths during heatwave periods in excess and the number of excess deaths per day (Green et al., 2016). In Europe and in comparable regions of the same climate zone, the daily death frequency shows an elevation in the winter months, with the highest mortality seen in February (Robine et al., 2012). Therefore, differences in the estimation of excess mortality will also vary according to whether the baseline period of measurement is a whole year or only specific months or seasons (Kovats and Ebi, 2006).

There is evidence that the occurrence of a heatwave changes the relationship between temperature and mortality (Lee et al., 2016). The mortality increase per 1 °C increase was much higher during a heatwave year, than in years without a heatwave. The definition of a

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heatwave might also influence its impact (Tong et al., 2010). Heatwaves are either defined as the exceedance of fixed absolute values or as a deviation from normal values (exceedance of a fixed percentile of all observed values) (Robinson, 2001). Moreover their definition includes the maximum temperature, the mean and the minimum temperature classified additionally by duration and timing during summer (ĎIppoliti et al., 2010). Considering the temperature distributions in different climate zones, the location in which an analysis is conducted also effects heatwave-related mortality (ĎIppoliti et al., 2010; Dong et al., 2016).

There is much evidence that advanced age and certain chronic illnesses (such as psychiatric dispositions or illnesses which limit self-care) are associated with higher rates of heat-related mortality (Hajat et al., 2010). A number of additional personal risk factors are discussed such as gender (Robine et al., 2012; Dong et al., 2016; Johnson et al., 2016).

This analysis aims to compare the 2003 heatwave with heatwaves in the following years to identify the possible influence of the "heat-health action plan for Hesse" (HHAP), introduced after the heatwave summer of 2003. The HHAP includes a heat health warning system, disseminated via the German Weather Service (DWD, Deutscher Wetterdienst) to hospitals and care homes for the elderly. In Germany, the heat warning system of the German Weather Service was set up nationwide in 2005 (Zielo and Matzarakis, 2017). A 2-stage warning process informs people of an imminent heat wave. Further measures include the distribution of leaflets, television or radio programmes and training selected professionals, such as staff in care homes, organized by various institutions such as regional healthcare administrations (Straff et al., 2017). The implementation of a heat health warning system along with a nationwide heat health action plan was recommended by the 2008 World Health organization (WHO) guidance (Matthies et al., 2008). These activities were implemented stepwise over a period of years. New activities, mainly aiming to inform and educate the public are still coming into force. Recently, there have been some efforts to monitor the existing heat health warning systems (Grewe and Blättner, 2012; Grewe et al., 2014). In addition, HHAPs of 8 European countries were analysed to assist in the development of a structured HHAP for Hesse (Grewe et al., 2014; Grewe and Blättner, 2012)

Monitoring the effects of heat on the population is important, since although heatwaves occur infrequently in the Middle-European region, but result in an increased mortality rate (Kovats and Ebi, 2006; Bernstein et al., 2007; Robine et al., 2012). This analysis adds to earlier work from 2013, with data from a recent heatwave in 2015 (Heudorf and Schade, 2014; Heudorf and Meyer, 2005).

2. Materials and methods

Mortality data were recorded as excess mortality without analyzing for "heat-related deaths". All deaths registered in Frankfurt and reported to the Federal Statistical Office from June, July and August in the years 2003–2013 were included. For the years 2014–2015, the data was anonymized from the Frankfurt death records collected by the Public Health department, Frankfurt. For the years 2003–2013, 18,610 mortality cases were included; for the period 2014–2015, 3387 cases were included.

Data for temperature (min., max. and mean) were derived from the "State Office for Environment and Geology Hesse" (HLUG, Hessisches Landesamt für Umwelt und Geologie). The HLUG operates meteorological monitoring stations including three stations in Frankfurt. Data were taken from the monitoring station Frankfurt Ost.

In this research work the definition of a "heatwave" refers to a period of at least 5 consecutive days (> 4 days) *with a daily maximum air temperature exceeding 32 °C*. According to the heat health warning system of the German Weather Service (Deutscher Wetterdienst, DWD) daily (perceived) temperatures higher than 32 °C are regarded as "severe heat stress". If temperatures are higher than 32 °C (on 2 consecutive days; Level 1), a heat warning will be declared. *The threshold of 32 °C is not fixed, but varies depending on the previous 30 days, in order to compensate for the effects of short term adaptation. Level 2 is defined as Perceived Temperatures higher than 38 °C.*

For statistical analysis, SPSS version 15 was used. The data were calculated for means in every series. Correlation between mortality (all ages, < 60, 60–79, ≥80) and the parameters temperature (mean, max., min.) were calculated. Bivariate correlations were estimated by Spearmans Rho. The Mann-Whitney *U* test was used to check the significance of factors contributing to excess mortality.

Excess mortality is described as percentage deviation from the mean. The mortality mean was calculated as cases of death in Frankfurt/Main in the months June–August in the years 2003–2015.

3. Results

Using the definition of at least five consecutive days exceeding a maximum temperature of 32 °C, the city of Frankfurt/Main has seen four heat waves between 2003 and 2015: 02/08/2003–13/08/2003; 18/07/2006–22/07/2006; 08/07/2010–12/07/2010; 01/07/2015–05/07/2015.

Table 1 depicts various indicators of temperature, the mortality rate and specific details of each particular heatwave. Including data from the heatwave of 2015, it can be shown that only in 2003 the mortality was extraordinarily high. The duration of the 2003 heatwave was also longer than in other years (12 days, versus 5 days duration in the years 2006, 2010 and 2015). In contrast, each heatwave was comparable in terms of temperature minimum, maximum and mean (e.g. max. temperature 2003/2015 38.5 °C/39.7 °C).

In Fig. 1A and B the, temperature (min., max., mean) and mortality of the summer 2003 and 2015 are shown. 2015 was chosen because of its peaks in the daily min., max. and mean temperature, which were even higher than that measured in 2003, meaning it was the most comparable. The period between the beginning and middle of August 2003 saw a heatwave of 12 days according to the definition of a maximum temperature of at least 32 °C for more than four days. Simultaneously the minimum temperature was above 20 °C, which in central Europe is defined as *tropical night* (definition by the German Weather Service, DWD).

It could be observed that even without the presence of a defined heatwave, mortality increased with rising temperatures, as seen in July 2003. During the 2003 heatwave the mortality increased rapidly with a delay of three days after the start of the heatwave, and fell immediately to normal when the heatwave ended. In 2015 there was also an increase in mortality, however it did not reach as high a peak as in 2003. Mortality associated with the 2015 heatwave, like that in 2003, increased three days after start of the heatwave and decreased when it ended.

As expected, there was a clear correlation between temperature (mean, min., max.) and mortality, especially in the elderly population (Table 2).

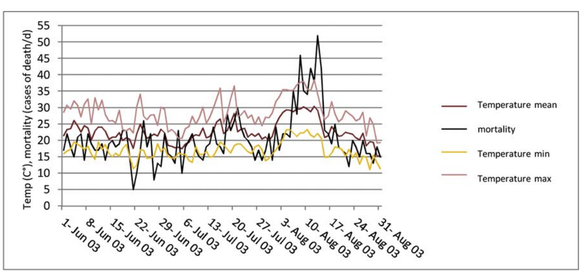
Fig. 2 illustrates the temperature extremes during heatwaves of the years 2003–2015. The figure demonstrates that the daily maximum temperature changes in parallel with the minimum temperature. In 2015 the maximum as well as the mean temperatures were higher than in the previous years. In 2003, the duration of a maximum temperature of higher than 32 °C was the longest (12d). Correspondingly, 2003 also had the longest minimum temperature higher than 20 °C duration (also 12d).

Excess mortality seen in the summer months in the years 2003–2015 is given in Table 3. In 2003, there was significant excess mortality in the total population, which was primarily due to excess mortality in the elderly population. The overall population only had an excess mortality in heatwaves of 2003, 2010 and 2015. No excess mortality during heatwaves was seen in the under 60 years old population, in any heatwave period. However, the older population showed a significant

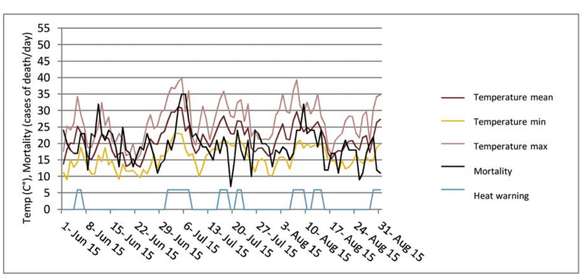
Table 1
Temperature (mean, min., max.), mortality and duration of heatwave in Frankfurt/Main, 2003–2015.

	Indicator for Temperature						Mortality		Absolute days 32 °C and higher	Heatwave	
	Mean Daily Temperature (C°)		Max. Daily Temperature (C°)		Min. Daily Temperature (C°)		Mortality (n/day)			HW, Longest duration/d	Longest duration of temperature > 20 °C/d
	Mean	Max	Mean	Max.	Mean	Max.	Mean	Max.			
2003[a]	22,8	30,4	28,5	38,5	17,0	23,3	20,4	52,0	21		
2003 Heatwave[b]	*26,5*	*30,4*	*33,7*	*38,5*	*19,1*	*23,3*	*32,7*	*52,0*		12	12
2004[a]	19,1	25,8	24,1	32,9	14,3	19,4	18,1	29,0	4		
2005[a]	19,3	26,8	24,4	34,3	14,2	20,2	17,6	28,0	4		
2006[a]	20,2	28,2	25,7	36,3	14,9	22,2	18,1	30,0	14		
2006 Heatwave[b]	*26,0*	*28,2*	*33,8*	*36,3*	*19,7*	*22,2*	*20,6*	*25,0*		5	1
2007[a]	19,2	28,1	24,1	36,7	14,4	21,2	17,8	33,0	3		
2008[a]	19,9	27	25,6	35,5	14,7	21,0	17,3	29,0	8		
2009[a]	19,7	27,9	25,5	37,1	14,2	19,6	18,6	29,0	5		
2010[a]	20,1	28,7	25,6	36,6	14,7	24,3	19,1	30,0	10		
2010 Heatwave[b]	*26,8*	*28,7*	*34,4*	*36,5*	*19,6*	*24,3*	*22,6*	*25,0*		5	2
2011[a]	18,8	26,5	24,2	35,0	14,0	19,3	18,0	32,0	4		
2012[a]	19,6	27,9	24,8	37,3	14,6	20,1	19,3	35,0	8		
2013[a]	20,3	30,4	25,9	37,5	14,7	22,8	18,3	28,0	12		
2014[a]	19,3	27,7	24,6	36,4	14,3	20,0	17,5	28,0	6		
2015[a]	21,2	31,1	26,9	39,7	15,6	23,1	19,3	35,0	19		
2015 Heatwave[b]	*26,9*	*31,1*	*34,1*	*39,7*	*20,1*	*24,3*	*25,4*	*35,0*		5	4

Every heatwave summer had one heatwave with the definition of > 4 days with temperature exceeding 32 °C max.
[a] Information provided for summerperiod (Jun–Aug).
[b] Information provided for corresponding heatwave.



X-axis: Time line for summer 2003 (June-August), Y-axis: Intensity of temperature (mean, min., max.) and mortality (cases of death/day)



X-axis: Time line for summer 2015 (June-August), Y-axis: Intensity of temperature (mean, min., max.), mortality (cases of death/day) and heat warnings

Fig. 1. A Temperature and mortality summer 2003 in Frankfurt/Main. B Temperature and mortality summer 2015 in Frankfurt/Main.

Table 2
Correlation between mortality and temperature (separated for age groups), 2003–2015.

Age (years)	all	< 60	60–79	≥80
Temperature (mean)	0.143**	0.021	0.067*	0.188**
Temperature (min)	0.138**	0.001	0.051	0.176**
Temperature(max)	0.137**	0.031	0.069	0.181**

* Significant < 0.05.
** Significant < 0.01.

excess mortality during all heatwaves, which was highest in 2003.

4. Discussion

4.1. Heatwave characteristics

The data shows that the excess mortality during the heatwave of 2003 was extraordinarily high, especially in the elderly population, compared to heatwaves that followed. Several issues can be discussed as potential explanations for this finding.

In order to prevent increasing mortality rates due to heatwaves in the future, early warning systems and heat health action plans were implemented in the years following the 2003 heatwave. In Hesse (the region including Frankfurt), the action plan involved the provision of information leaflets for the general public as well as for professionals. Numerous training opportunities were also offered to health care units, nursing homes and specialists (doctors, nurses, geriatrics) to assist in the management of heat-induced health problems. In addition, authorities conducted inspections of retirement homes, which house the most at risk population (the over 60′s) to check for compliance with the recommendations.

In the years 2006, 2010 and 2015, heatwaves occurred based on the definition of a heatwave as ≥32 °C for more than 4 consecutive days. The excess mortality in these years did not reach the level seen in 2003, even though individual temperature parameters (mean, min, max) were higher in 2015. One major difference in 2003 compared to the following years was its exceptionally long duration (12 consecutive days in 2003 versus 5 consecutive days in 2006, 2010 and 2015). Therefore, we hypothesize that the duration of a heatwave is used as a better marker for excess mortality than temperature alone. Other studies also show an increase in mortality with occurs after an initial delay of 3–4 days, which supports the finding that a longer duration of the heatwave leads to a disproportionately high excess mortality (Heudorf and Schade, 2014; Borrell et al., 2006).

In identifying a predictive factor for *heat stress*, the longest duration of a certain minimum temperature could also be taken into account. Table 1 shows an overview of the "*longest duration of daily temperature higher than 20 °C*" (the definition of tropical night in a moderate

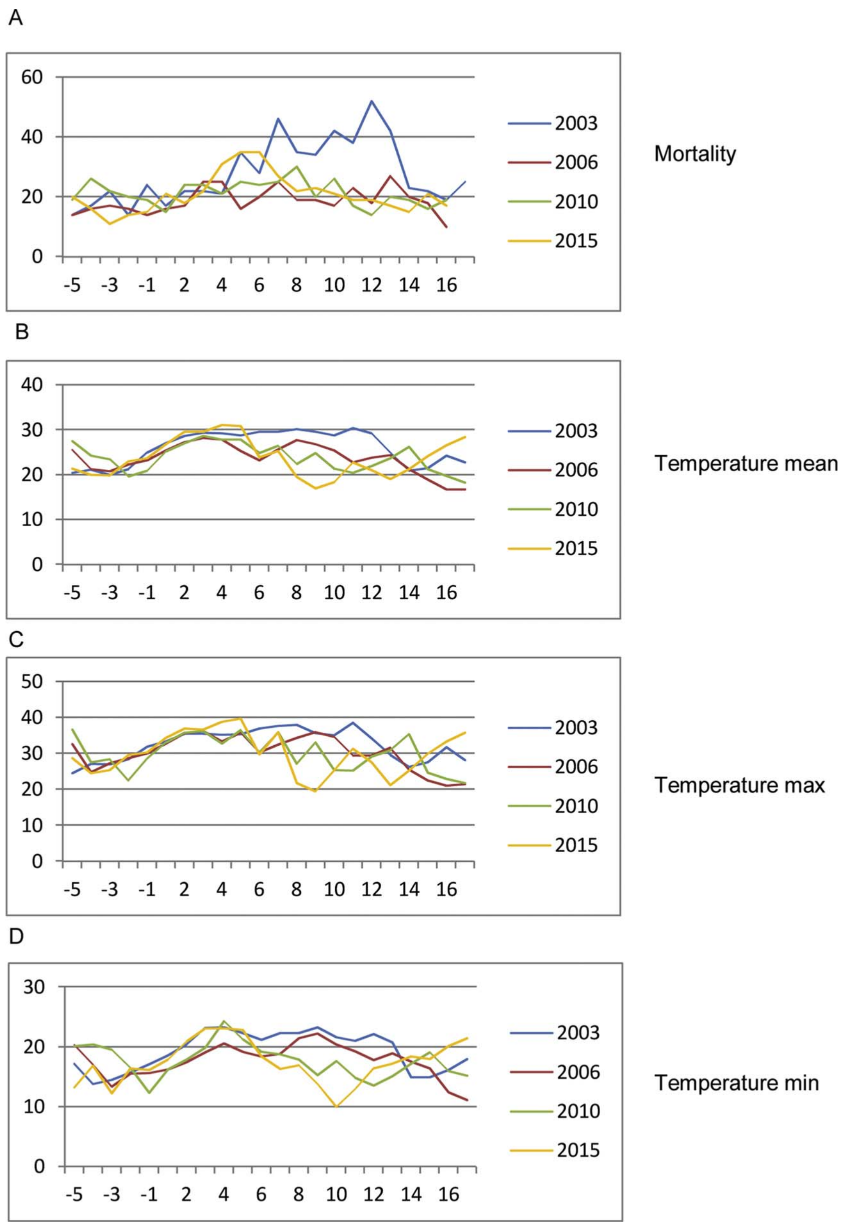


Fig. 2. Mortality and Temperature (mean, max., min.) during heatwaves.
X-axis: Day of heatwave starting from 5 days before first day of heatwave; Y-axis: A: Mortality (cases of death/day); B: Temperature mean (°C); C: Temperature max. (°C); D: Temperature min. (°C)

climate). This value was shown to be highest in 2003, which also had the biggest excess mortality recorded between 2003 and 2015 (77.8%, see Table 3).

4.2. Heat wave definitions and climate zones

A British survey analyzing data from 2003 to 2013 also dealt with the impact of heatwaves on mortality. The excess mortality was estimated here as the cumulative excess death during the heatwave period,

Table 3
Excess mortality during heatwaves 2003–2015, Frankfurt/Main, Germany.

	All		< 60 years	Excess Mortality (%)	60–79 years		≥ 80 years	
	Mortality (cases of death/d) mean	Excess Mortality (%)	Mortality (cases of death/d)mean		Mortality (cases of death/d) mean	Excess Mortality (%)	Mortality (cases of death/d) mean	Excess Mortality (%)
Heat Waves								
2003	32,7	77,8**	3,1	12,2	12,3	63,8**	17,3	113,4**
2006	20,6	12	2,9	3,6	6,9	−8	10,8	33,3*
2010	22,6	22,7*	2,9	2	8,6	14,3	11,1	37,6*
2015	25,4	38,1***	2	−29,6	9,4	25,3***	14,4	77,8***

***significant $p < 0.05$.
**significant $p < 0.001$.
*significant $p < 0.01$.

based on variability in deaths during non-heatwave periods. The survey showed that in the UK during the heatwave of 2013, the mortality rate was less than expected in comparison to that seen in the heatwave years of 2003 and 2006 in the UK. To compare these data to the Frankfurt/Main data, the definition of a heatwave has to be taken into account: In GB, a heatwave is defined with the aid of the *National Alert Level*. These Alert levels range from max. daytime temperature of 28 °C with a nighttime temperature of 15 °C in the North East to 32 °C/18 °C in London (Green et al., 2016). The Alert levels were defined by the *National Severe Weather Warning System*. In the 2013 heatwave, the highest Central England temperature values were 22.7 °C (mean daily temperature) and 29.7 °C (max. daily temperature). The survey reports two periods of 13 days and 6 days in 2013.

In an Iranian analysis using data from 2001 to 2011 from Tehran, a complex heatwave definition was applied requiring either 3 consecutive days with a maximum temperature above the 90th percentile (37.8 °C) or 3 days with minimum temperatures above the 90th percentile and maximum temperature exceeding the monthly mean by +5 °C (Ahmadnezhad et al., 2013). The basis for the mortality rate was calculated for May-September (Ahmadnezhad et al., 2013). Following this definition, Tehran experienced 17 heatwaves between 2001 and 2011. In comparison, Frankfurt/Main had (according to our definition) three heatwaves in the same time period.

The percentage excess mortality rate in Tehran was highest during the heatwave of 2009 with 19.2%. Comparing this with the Frankfurt data (Table 3): the excess mortality in Frankfurt during heatwaves was shown to be considerably higher, e.g. 77.8% in 2003 in the overall population and 38.1% in 2015. Regarding the data from the Iranian analysis it becomes clear that a comparison is difficult because of technological and environmental differences, such as the widespread use of air conditioning in apartments in Tehran. Beside this the human adaptation to warm temperatures of the population has to be considered. Even though there were numerous heatwaves in Tehran/Iran between 2001 and 2011 the highest excess mortality was lower than during heatwaves in Frankfurt/Germany.

Other research groups have addressed the issue of varying heatwave definition An Australian examination of data from the city of Brisbane (tropical climate) between Jan 1996 and Dec 2005 compared different heatwave definitions (Tong et al., 2010) and showed the impact of definition differences in the size of heat-related impact on the mortality. This authors concluded that local definitions of heatwave should be defined and the health effects be interpreted at a regional level (Tong et al., 2010).

A French analysis used data from 16 European countries (moderate climate) to show age and gender-specific mortality between 1998 and 2003 (Robine et al., 2012). They could also show higher mortality in the winter months. In the summer period (June–September) the number of deaths is low and varies little between the months, but in the following eight months there is a phase of steady increase between October to December, then a central winter phase, where the numbers of deaths are high and display significant variation. Finally there is a phase of steady decline in the number of daily deaths between March and May (Robine et al., 2012). This distribution of daily death frequency will most likely not be replicated in a tropical climate or desert environment. Such differences should be taken into account when comparing heat mortality surveys from different countries, particularly when annual totals rather than select month totals are used. Taking the summer months as a basis for mortality makes a description of excess mortality during heat periods possible (especially in moderate climate). Taking the whole year as a basis would probably not show an excess mortality of the heatwave days, since the influence of the winter months has a much stronger account on mortality (Robine et al., 2012).

4.3. Heatwaves and the elderly population

Some research work has focused on the special risk for the elderly population to suffer from heat wave complications (Robine et al., 2012).

Some research activities addressed the issue of implementing heatwave action plans (Abrahamson et al., 2008). Since it has been shown in numerous publications that the elderly are particular at risk for heat-related mortality, potential methods of effectively targeting this at risk population have been investigated (Bunker et al., 2016; Johnson et al., 2016). In a British study for example, 73 interviews with participants between 72 and 94 years of age were conducted. It was shown that few participants considered themselves either old or at risk from the effects of heat. The study concluded that a more population-based information strategy was therefore more appropriate (Abrahamson et al., 2008).

4.4. Effects of a “heat health action plan”?

In the present analysis covering the time period before the implementation of a *heat health action plan* (implemented after the 2003 heatwave) and after up to 2015, it could be shown that excess mortality did not again reach the heights seen in 2003. However, due to the lower duration of the heatwaves after 2003, this reduction cannot solely be attributed to the implemented HHAP.

It should be discussed how to address senior residents effectively, especially in light of the British research study (discussed above) that indicated few senior persons (aged 72–94) consider themselves at risk from the effects of heat (Abrahamson et al., 2008), though this group fall into the most vulnerable group. Some media forms may be better than others at targeting members of this high-risk group, and requires further analysis (e.g. Radio, TV, newspapers).

4.5. Limitations

The results are based upon the Frankfurt death records, which include information about age and gender but not the cause of death. Information about the living circumstances (nursing home, apartment), details of housing development (ground floor, top floor; roof characteristics) and other personal factors were also not available for analysis.

Temperature data was collected from the Hessian “State Office for Environment and Geology” from one monitoring station in Frankfurt-East. Local differences were not evaluated.

4.6. Conclusion

This research work aimed to compare the heatwave of 2003 with the following heatwaves of 2006, 2010 and 2015 to evaluate the measures of the Hessian *HHAP,* introduced after the 2003 heatwave. In analyzing data from the city of Frankfurt (Main) it was shown that the excess mortality in Frankfurt did not reach the numbers of 2003 in the following heatwave periods (2006, 2010, 2015).

The 2003 heat wave duration was exceptionally long in duration (12 days), unmatched by the heatwaves of 2006, 2010 and 2015. Since our data show that the duration of a heat wave is strongly associated with the mortality, the lower mortality of the years 2006, 2010 and 2015 is unlikely to be attributable to the implementation of the Hessian HHAP.

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